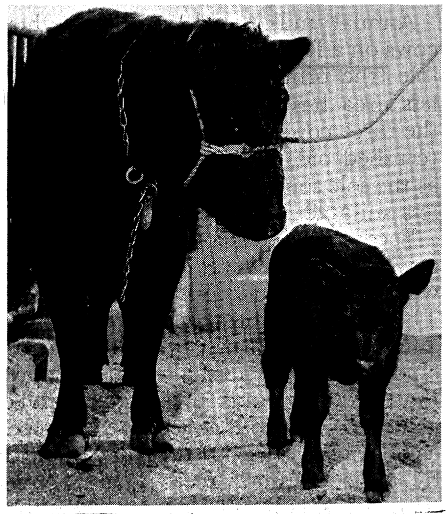


Proud mother at Beltsville, Md., *above,* has something besides her calf for USDA researchers to brag about. This Angus cow ate only synthetic feed in the 3 years since she was weaned. Her calf is normal. *Below right,* Animal Husbandman Robert B. Oltjen squeezes handful of the synthetic feed through his fingers. These photos deal with some of the same subject area, but are unrelated to Dr. Virtanen's work in Finland.

first time that the cow is able to achieve a moderately high milk yield without any protein, using urea and ammonium salts as the sole source of nitrogen. This surprising result opened new views about the cow's ability as a producer of protein.

Adaptation of cows to the test feed is best achieved by gradually removing normal feed and adding test feed in corresponding amounts during about 2 months before calving. The cows were fed twice a day. Cows with a high milk production eat their large feed rations intermittently, with some rest periods, and thus they themselves regulate the intake of urea.

Estrus of the test cows has been regular, but the cows with the highest milk production needed a bull's services many times before they became pregnant. The long lactation period and high milk production per lactation resulted from this situation.

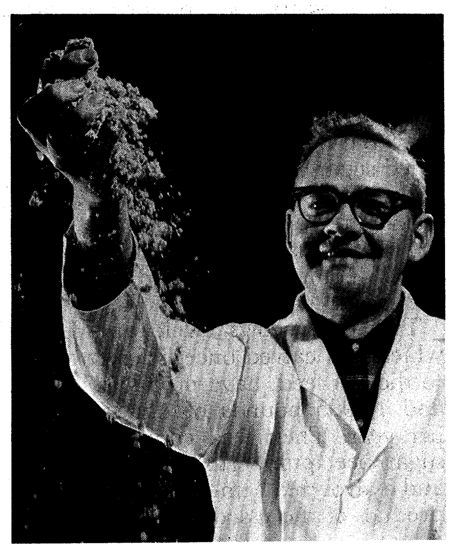
Great changes occur in the microbial population of the rumen content when cows are transferred to synthetic feed. Protozoa (microscopic single cell animals) generally disappear entirely or decrease enormously, while the number of bacteria rises manyfold.

This leads to a better use of ammonium nitrogen for the synthesis of bacterial protein.

Milk produced on synthetic, protein-free feed is called in our laboratory zero milk (0-milk). Composition of 0-milk is very similar to that of milk rich in fat and protein produced on normal feed. Average fat content of 0-milk has varied from 4.5 to 6.3 percent (with normal feed, it is 3.6 to 4.7 percent) and the protein content from 3.8 to 4.3 percent (normal feed: 3.2 to 3.9 percent). Only the sugar (lactose) content of 0-milk has been somewhat lower than normal milk, from 4.4 to 4.7 percent (with normal feed, it is 4.8 to 5.1 percent).

Amino acid composition of the total protein of 0-milk is so similar to milk produced on normal feed that no real differences have been found. Individual milk proteins are similar in 0-milk and normal milk.

On the basis of taste tests, the flavor of 0-milk is very similar to that of normal milk. Chemical analysis of flavor substances has confirmed re-



sults of the taste tests. Normal flavor substances of milk are thus formed in the cow's organism and are not due to the feed used. This does not mean that some flavor substances of plants could not pass into milk in trace amounts, inadequate to produce a flavor effect in milk. Only plant substances with a strong repulsive odor are known to cause off-flavors in milk observable in taste tests.

The content of water-soluble vitamins in 0-milk is approximately at the same level as that of normal milk. Thus, the vitamins seem to be formed to a sufficient extent by the rumen bacteria. Vitamin A- and D-content in the 0-milk depends on how much of these vitamins is given to the cows.

Composition of the fat of the 0-milk depends on the quantity and quality of the fat fed. When about 5 ounces of vegetable oils are included per day, composition of the fat of 0-milk has corresponded approximately to the fat of milk produced on normal feed. Further increase of vegetable oil in the feed causes a decrease in the fat content of 0-milk.

Results obtained on a protein-free synthetic feed have given impetus for a study of how great an amount of urea can be used in dairy rations containing normal feed low in protein.

For 2 years, we performed such experiments with six cows. In the results so far, one cow (Lila) which calved for the first time has produced 10,743 pounds of standard milk per year on a feed containing potatoes, dried sugar beet pulp, and hydrolyzed hemicellulose from wood as energy nutrition.

The annual milk yield is about 11,905 pounds of standard milk after the second calving.

Two other cows (Kelo and Lelo), which had calved once before transfer to the test feed, have produced 11,466 and 11,905 pounds of standard milk per year. Their feed contained dried sugar beet pulp, crushed oats, barley, and hydrolyzed hemicellulose—a waste product of the wood industry.

Annual milk yield of three other cows on a feed containing more digestible true protein and correspondingly less urea has remained below that of the three cows mentioned first. Cereals (crushed oats and barley) and sugars as the sole source of carbohydrate seem less suitable for milk production.

Feeding experiments with only a few cows do not, of course, give results from which firm conclusions can be drawn. They will, however, give some guidance. On this basis, it can be concluded that the annual yield of more than 8,800 pounds of standard milk achieved on a protein-free synthetic feed can be raised to 11,000 to 12,000 pounds by using common feed poor in protein. It is still unclear whether the increase in milk production is due to the digestible true protein contained in the feed used or to other types of feed components stimulating bacterial growth and promoting feed intake.

Our results show that the proteins have lost their dominant position in the feeding of milking cows, even at a fairly high level of milk production. Thus, new possibilities for milk production have opened even in areas where common feed, especially grass, cannot be cultivated. By this I mean tropical regions in particular, where the greatest part of mankind lives and where long dry periods prevent cultivation of grass. In these regions, it is possible to produce harvests of plants rich in starch and sugar but poor in protein, which can be used for feeding milk cows when supplemented with large amounts of urea. In regions rich in forests, wood hemicellulose can be used in cattle feeding along with urea.

In general, the demonstration that protein can be replaced by urea to the extent of 60 to 80 and even 100 percent in the feed of dairy cattle extends the possibilities for milk production all over the world.

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Will Cows on Synthetic Diets Help End World Protein Hunger?

ARTTURI I. VIRTANEN

In the developed countries, a great part of protein in food comes from milk, dairy products, and meat which contain all of the amino acids needed by the body in order to synthesize its proteins.

In developing countries overcrowded with people, the protein of cereals—poor in some essential amino acids—is almost the sole source of protein. General malnutrition is mainly due to this, because with the deficiency of even a single essential amino acid the body cannot synthesize all its necessary proteins. Yet despite the great value of milk and meat as a source of protein, it has lately been questioned whether animal production should be emphasized for future food needs since animals are too inefficient in converting feed to food.

Milk production has the highest efficiency in regard both to feed and protein. Theoretically, the cow should be the domestic animal best adapted to live in the world of the future. And new experiments with synthetic feeds seem to increase the cow's capabilities most dramatically.

The unique digestive tract of cows and most other ruminants has a large stomach, called the rumen, at the beginning of the tract. In the rumen, the feed is digested by the numerous microbes there.

Carbohydrates form the most important energy source of cows. Feed carbohydrates are fermented mostly to volatile fatty acids, which are transferred into the blood. Simultaneously, protein is formed in the rapidly dividing and growing microbial cells from the nitrogen compounds in the feed. When the microbial cells in the flow of rumen contents reach the fourth chamber of the digestive system and the small intestine, the cells are digested, and their proteins are split to amino acids. These are absorbed into the bloodstream and are used for protein synthesis as in other mammals.

Many ruminal bacteria grow well with ammonium salts as the sole source of nitrogen. But to what extent this happens in the cow's rumen has been obscure. Urea is a cheap synthetic chemical today and a common nitrogen ingredient of fertilizer. The nitrogen in this compound is readily converted to ammonia by bacteria, of which there are great numbers in the cow's rumen.

Many feeding experiments in different countries with urea have led to the conclusion that only a small part—maybe 15 to 20 percent—of the protein requirement of milk cows can be replaced by urea. High protein content in feed has therefore seemed necessary for milk production.

In the spring of 1958, I arranged an

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experiment where a cow on normal feed was fed ammonium nitrogen in which a part of the usual elementary nitrogen of atomic weight 14 was replaced with the uncommon nitrogen of atomic weight 15, a heavier form of nitrogen which can be readily detected by physical analysis of any compound containing it. Since all amino acids contain nitrogen and all proteins are made up of amino acids, this test for heavy nitrogen enables one to decide if the nitrogen of an ammonia molecule ends up in a specific amino acid or protein. In this experiment, the amino acids of the cow's milk proteins contained heavy nitrogen, thus showing that dietary ammonia can be converted in part to the amino acids and proteins in milk.

Our body requires eight essential amino acids in our diet; if any one of these is missing or present in an inadequate amount, we develop malnutrition. Animals, including the cow, likewise require eight to 10 preformed amino acids in their diets. The experiments to be described below show that the cow under proper dietary control and with the help of micro-organisms in her stomach can synthesize to some degree all her essential amino acids.

This experiment showed definitely that ammonium nitrogen had been utilized for synthesis of all the components of milk protein. The experiment was repeated several times with the same result. Amino acids of the milk proteins contained heavy nitrogen to a considerable extent in as little as 3 hours after feeding the heavy nitrogen. Of the amino acids of the milk proteins, essential histidine picked up the heavy nitrogen most slowly. It is thus possible that histidine formed a bottleneck in protein synthesis.

When at the beginning of the 1960's we started to investigate whether the normal flavor substances of milk are formed within the cow's organism or whether they are due to the feed, it was important to try to produce milk on the simplest feed containing as few flavor substances as possible. The planned feeding consisted of 55 percent purified starch, about 25 percent wood cellulose, and about 20 percent granulated sugar, with urea and a little ammonium sulfate and phosphate as the sole source of nitrogen.

Besides organic matter, a cow's feed must contain all the 16 mineral elements known to be necessary for normal health. These include appreciable amounts of iron, calcium, potassium, and sodium, plus traces of many other inorganic substances. In a purified synthetic diet, these are ordinarily supplied as a mixture of salts, called a salt mixture. These feedstuffs were given mainly as briquettes. As fat, a small amount of vegetable oil was used. Of the vitamins, A and D were given as synthetic preparations.

The feeding experiments were started in the autumn of 1961 with one cow, and new cows have been included since 1962. All the test cows were Ayrshires, with an average weight of about 1,000 pounds.

On a protein-free synthetic feed, the cows produced 4,400 to 6,000 pounds standard milk per year (standard milk=4.0 percent fat, 3.2 percent protein, and 4.9 percent sugar) during the first 2 years, when the amount of urea fed was relatively low, at the most 1 pound per day. As it was observed during the experiments that there was no danger to the cow's health even when feeding a greater amount of urea, the dose of urea was raised gradually so the ration of urea plus ammonium salts corresponded in the autumn of 1966 to 1½ pounds of urea per day.

The increased urea had a favorable effect on milk yield, and the highest amount of urea enhanced the milk's protein content. Annual yield of the test cow Metta (born 1955, calved six times on normal feed, twice on experimental feed) in 1964–65 was 9,297 pounds standard milk on an energy basis; during 1966–67, her yield was 9,060 pounds.

The test cow Jairu, born during 1961, produced in a year (1965–66) 8,448 pounds.

Thus, it was demonstrated for the